Variability of Irradiance in the Wave Boundary Layer

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LONG-TERM GOALS

Our primary goal is improve our understanding of the role of surface waves, bubble clouds, and near-surface oceanic processes on the spatial distribution of oceanic irradiance.

OBJECTIVES

The objectives are to:

- Measure the variance in the oceanic light field.
- Measure turbulence velocity and temperature fluctuations in the water column.
- Associate the variance in the light field with surface waves and variance in the inherent optical properties and physical properties.

APPROACH

This year we modified our approach because of the desire to operate under high wind conditions. Therefore we prepared for both ship-based vertical profiling and AUV-based spatial survey programs. Instead of using the large Bluefin AUV that we have operated in the past, we contracted with Mark Moline's group at Cal Poly to operate their REMUS-100 vehicle with scattering, chlorophyll, and seven channel irradiance sensors. The smaller vehicle is easier to retrieve in higher seas. While easier to retrieve our ability to launch and retrieve the AUV was dependent on being able to launch a small boat from the Kilo Moana, which did limit the number of AUV operations during the August-September 2009 field experiment.

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The AUV-based Rockland Scientific Inc (RSI) microstructure package was modified to free fall vertically (Figure 2). We also built a small optical profiler that could be used to characterize optical properties away from the ship and to collect coincident IOP (a, c, bb) and radiometric (Ed Lu) properties from the ship. To achieve high-resolution irradiance measurements we integrated two Biospherical single wavelength irradiance sensors into the RSI microstructure package (hereinafter referred as vertical microstructure profiler (VMP; Figure 2). This sensor has the high sampling rate that is needed to achieve small, spatial-scale irradiance measurements. The VMP was deployed in a profiling mode to determine microstructure properties. We deployed it with a small float to reduce the decent rate to get higher resolution irradiance profiles. We also attached it to a larger float to collect time series at fixed depths near the surface. The large float allowed the system to follow the swell, but did not respond to small waves so the depth variations were tens of centimeters in 2-3 m waves.

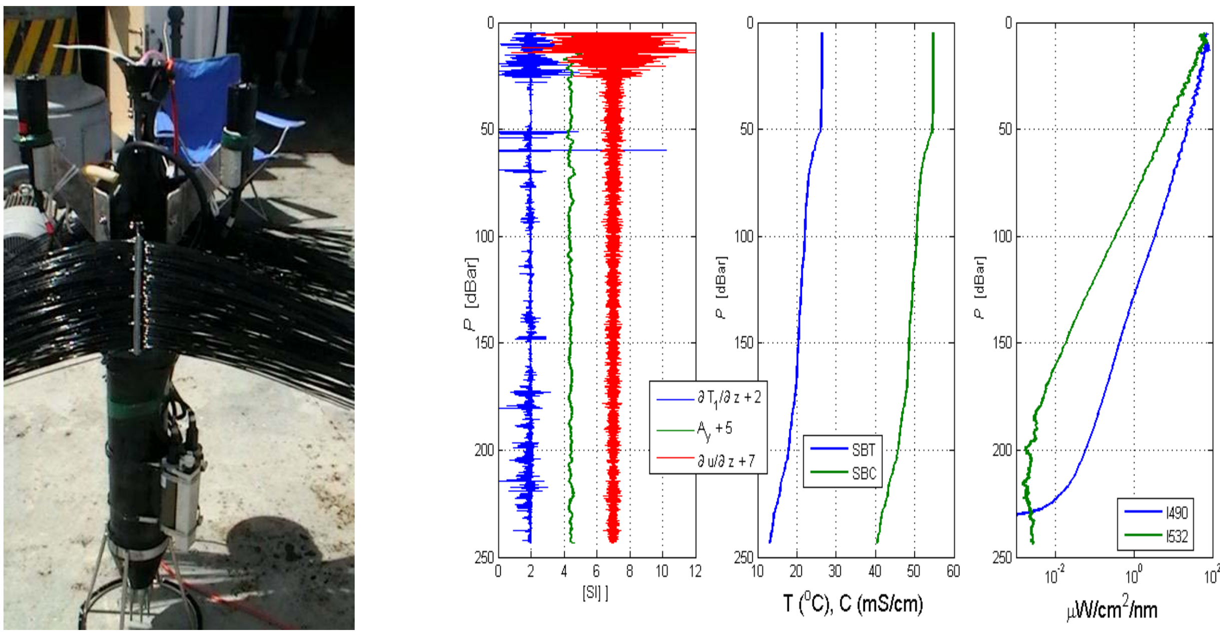

Figure 1. Left Panel: The VMP microstructure profiler prepared for deployment. The high speed temperature and shear probes are at the bottom and irradiance sensors are mounted at the top. Right Panels: Example of a VMP profile taken on Aug 29, 2009 at 13:35-13:40 local time. (a) High frequency temperature gradient (blue), one component of horizontal acceleration (green), high-frequency shear (red). (b) SeaBird T and C (middle panel), and (c) irradiance at 490 nm (blue) and at 532 nm (green).

The AUV is being flown along several isobars to measure the light field, IOPs and physical properties. Along each isobar it is possible to determine the power spectrum of irradiance fluctuations and provide other statistics related to the variability in the light field. These statistics can then be compared to the variability in modeled light fields. The AUV is also being used to measure the variability in physical and optical properties near FLIP and the Kilo Moana (Figure 2).

A vertical optical profiler (hereinafter referred as VOP) was also constructed to collect inherent and radiometric optical property measurements when the AUV was unable to operate. These measurements provide a more complete time series of optical variability when combined with the

measurements of Twardowski et al. A bioluminescence sensor was also added to the profiler during night time operations.

WORK COMPLETED

Analysis of Date from Santa Barbara, 2008 Experiment: We have examined horizontal variability of irradiance and high-frequency temperature records collected from Bluefin AUV. A couple of manuscripts are in preparation and some of observations are presented in the RESULTS section.

Hawaii, 2009 Experiment: We converted the microstructure sensors to a vertical profiler and trained with the new configuration between cruises. We also trained with the group from Cal Poly on the use of the REMUS, and removed the optical sensors from the OSU Bluefin for use as an optical profiler. All of these systems were used during the field experiment in August and September of 2009. We have collected 325 VMP profiles (Figure 2), and 42 VOP profiles covering three phases of the day (mooring, midday, and nighttime). We feel that we have enough to analyze in order to meet our scientific objectives. The number of AUV runs (e.g., Figure 3) was limited to three because its operation has been limited by our ability to launch the small boat for retrieval in the higher sea state conditions experienced during the experiment.

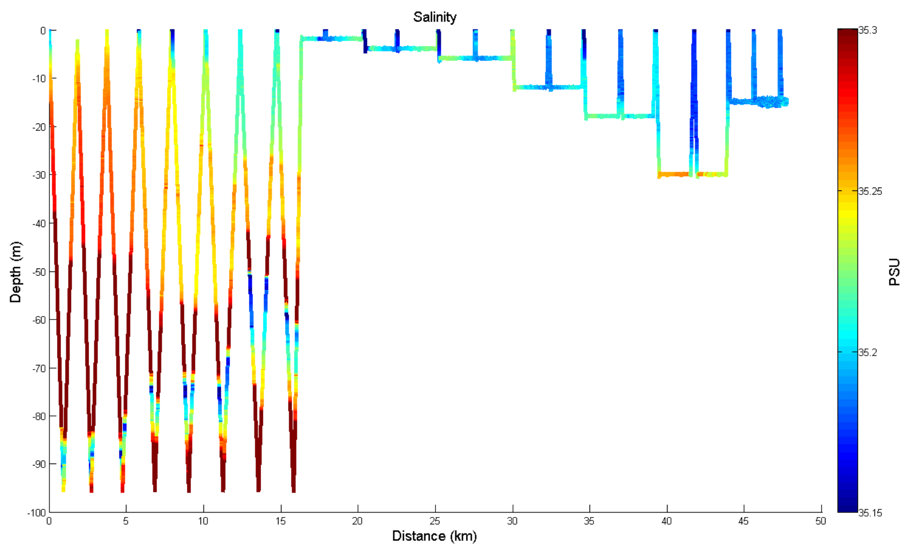

Figure 2. A trace of the salinity (color) as a function of depth (y-axis) and distance traveled by the AUV is shown. The profiles at the beginning are a map of the values along the drift of the ships, and shows that there a change in surface and subsurface salinity does occur. A fresher subsurface layer is observed below the main halocline.

RESULTS

During the 2008 experiment off Santa Barbara the AUV was used in a profiling mode as well as running at fixed depths. During the runs at twenty meter depth we observed short wavelength (~40m) internal waves (Figure 3). These waves have an estimated wave height of three meters and a phase speed of 0.1 m/s. High frequency temperature fluctuations were observed to be associated with these

waves indicating that they are important to turbulent mixing. The short wavelength of these waves makes them difficult to observe using CTD profiles or ship-based towed bodies, thus their importance to shelf dynamics may be underestimated.

Another result is that the irradiance fluctuation measurements were found to be dependent on the direction the vehicle moved relative to the surface waves (Figure 4). When traveling from south to north there is more energy at the shorter spatial scales than when the vehicle was traveling west to east. This result indicates that the wave field was at least partially polarized, which allowed the AUV to travel along a focal line in one direction and perpendicular to focal lines in the other.

The short wave number fluctuations also decreased as a function of depth (Figure 5). This is a result of the defocusing caused by scattering in the water column. Near the surface fluctuations are observed down to scales of a few centimeters, which is the resolution of the sampling technique. By the time the instrumentation is at six meters depth the fluctuations on scales less than 10 centimeters has decreased by an order of magnitude. By twelve meters they have decrease three and a half orders of magnitude at the 10 cm scale and are effectively in the noise floor. Light fluctuations were still observable down to thirty meters depth. The peak at 4×10^{-2} is caused by vehicle motion as it tries to follow an isobar. The shorter peaks are likely to be associated with waves of different wavelengths.

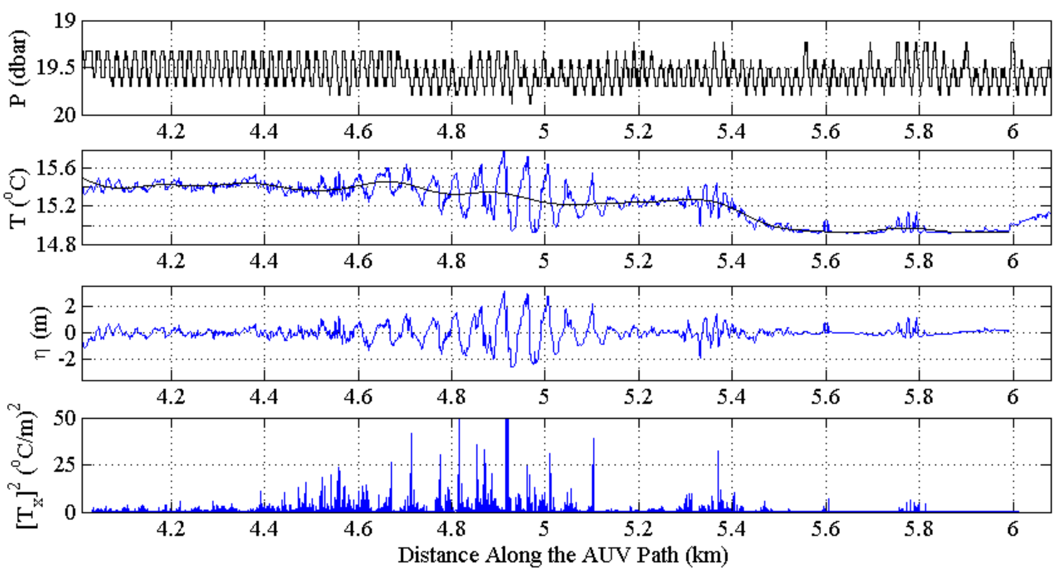

Figure 3. Packet of internal waves observed at 20 m depth on September 20, 2008. Top panel shows the pressure record of the AUV indicating its vertical undulation on this level flight. The AUV has a control cycle of period of 11 seconds which is about 22 m for a speed of 1.9 m/s. The temperature field shown in the second panel from the top shows internal waves with wavelengths of approximately 40 m. The estimated vertical displacement is plotted in the 3rd panel from the top. The small-scale squared temperature-gradient illustrates elevated mixing rates associated the packet. These short wavelength internal waves are not typically observed using standard towed-undulating measurement platforms.

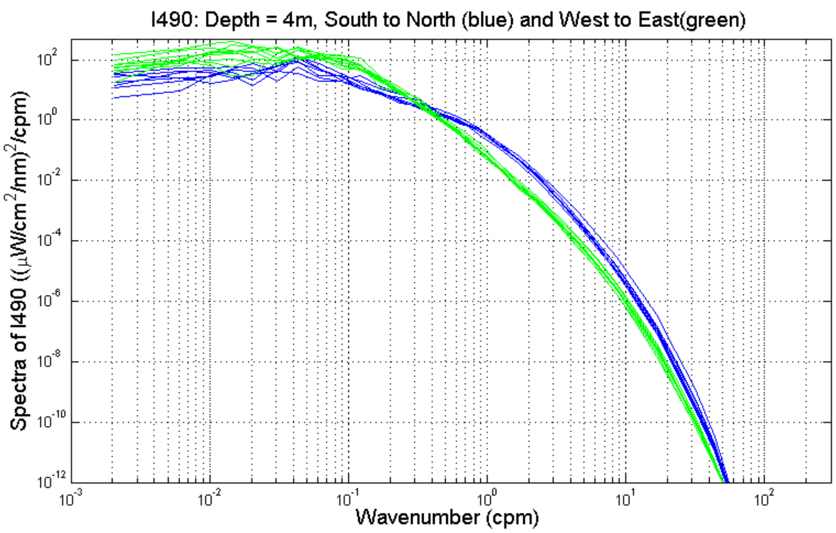

Figure 4. Wave number spectra of irradiance at 490 nm on Sep 22, 2008 when the vehicle was moving in two directions at a single depth. Wind was about 2-4 m/s coming out of west. Sky was clear with shortwave flux of about 600-700 W m^{-2}. When traveling south to north (blue lines) the spectra have more energy at shorter wave numbers than when traveling west to east (green lines).

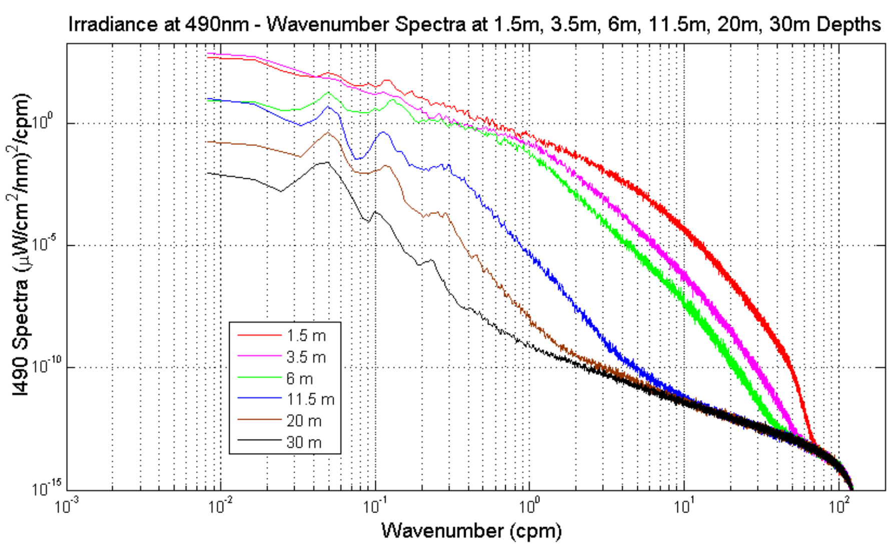

Figure 5. Shown is the wave number spectra at six depths for irradiance at 490 nm observed on Sep 20, 2009. Westerly winds were about 6 m/s and solar insolation varied from 650 to 850 W m^{-2} during the observation. The fluctuations at shorter wave numbers decrease rapidly with depth.

IMPACT/APPLICATIONS

None

RELATED PROJECTS

Other projects participating in the RaDyO program. http://www.opl.ucsb.edu/radyo/